# FUTURE DIRECTIONS

## SATELLITE OBSERVATIONS OF TROPOSPHERIC CHEMISTRY

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The troposphere is an essential component of the earth's life support system as well as the gateway for the exchange of chemicals between different geochemical reservoirs of the earth. The chemistry of the troposphere is sensitive to perturbation from a wide range of natural phenomena and human activities. The societal concern has been greatly enhanced in recent decades due to ever increasing pressures of population growth and industrialization. Chemical changes within the troposphere control a vast array of processes that impact human health, the biosphere, and climate. A main goal of tropospheric chemistry research is to measure and understand the response of atmospheric composition to natural and anthropogenic perturbations, and to develop the capability to predict future change.

Atmospheric chemistry measurements are extremely challenging due to the low concentrations of critical species and the vast scales over which the observations must be made. Available tropospheric data are mainly from surface sites and aircraft missions. Because of the limited temporal extent of aircraft observations, we have very limited information on tropospheric composition above the surface. This situation can be contrasted to the stratosphere, where satellites have provided critical and detailed chemical data on the global distribution of key trace gases (e. g. UARS, http://uarsfot08.gsfc.nasa.gov/).

Satellite observation of tropospheric composition is considerably more difficult than for the stratosphere because of the complexities involved in accounting for effects due to clouds, aerosols, water vapor, and the ozone layer overhead. To date, tropospheric chemistry observations from space are limited to a few weeks of CO measurements from the MAPS (see acronyms below) instrument aboard the space shuttle, indirect inferences of tropical ozone from satellite measurements of the total ozone column, and preliminary data sets for the column content of a few species ($O_3$, $NO_2$, HCHO, $SO_2$, BrO) from the GOME solar backscatter instrument launched in 1995. These measurements provided no information on the vertical structure of these species within the troposphere. The MOPITT instrument, a gas correlation spectrometer launched in December 1999, is expected to provide global observations of CO starting in mid-2000 with reasonable vertical resolution. Also launched on the same satellite was MODIS, which has aerosol column measurement capabilities well beyond those of earlier sensors.

GOME and MOPITT herald the era of tropospheric chemistry measurements from space. Two major launches over the next few years are the ESA ENVISAT satellite (mid 2001; http://envisat.estec.esa.nl/) and the NASA AURA (previously known as CHEM) satellite (late 2002; http://eos-chem.gsfc.nasa.gov/). ENVISAT will include (1) MIPAS, a high-resolution FTIR spectrometer observing in the limb, and (2) SCIAMACHY, a solar backscatter instrument with both nadir and limb viewing capabilities. AURA will include (1) HIRDLS, a limb-scanning IR radiometer with high vertical resolution; (2) MLS, an advanced version of the same instrument flown on UARS; (3) OMI, a solar backscatter instrument that observes radiation in the visible and UV; and (4) TES, a high-resolution FTIR spectrometer observing in both the limb and nadir. The instruments on board ENVISAT and AURA will provide the first space-based vertical profiles of a suite of gases in the troposphere. Not only ozone but its key precursors (e. g. $NO_x$) may be globally mapped.

Table 1 compiles the principal satellite instruments expected to provide information on tropospheric composition over the next few years. Only those standard products for which retrieval capability has been carefully assessed are listed in the Table. The high-resolution spectroscopic measurements from MIPAS and TES have the potential to yield data on a large number of additional species. TES could provide global maps of species such as $H_2O_2$, acetone, methanol, HCN, $HNO_4$, $SO_2$, and PAN. There are plans for new launches within the next 3-5 years (e. g. GOME-2, IASI, PICASSO) which will provide a great deal more information on the distribution of gases and aerosols in the troposphere.

All satellite instruments in Table 1 are on polar orbiting platforms, which have the advantage of global coverage but the disadvantage of data sparsity (return time over a scene is typically a few days). Geostationary observation, which allow instruments to stare at a scene for an extended period, would be of considerable value for studying patterns of pollution outflow from large-scale source regions. The GIFTS instrument, an FTIR spectrometer recently selected by the NASA New Millenium Program for launch on a geostationary platform in 2003, will provide the first geostationary data for tropospheric CO and possibly ozone. Instruments such as GIFTS may prove critical for the design and monitoring of international agreements controlling the export of environmentally important gases from geopolitical entities.

The growth of population and rapid industrialization in the developing world will lead to further globalization of air pollution concerns. Cumulative increases in global emission may tend to offset attempted improvements in local emission controls. Within the next 5 or so years, many studies will be performed to investigate the export of air pollution from major regions around the world. Satellite sensors will clearly be the platform of choice for such studies. These will allow the first detailed testing of global models of tropospheric chemistry.

In conclusion, the oncoming era of satellite observation could revolutionize tropospheric chemistry research. The limitations of satellite observations with regard to vertical resolution, precision, and the suite of observable species must however be kept in mind. These limitations can be overcome by in situ measurements from aircraft. Satellite and aircraft missions thus naturally complement each other, and a challenging task in the years ahead will be to design campaigns that take full advantage of this synergy to advance our scientific knowledge.

**Acronyms:** ESA: European Space Agency, FTIR: Fourier Transform Infrared Spectroscopy, GIFTS: Geostationary Imaging Fourier Transform Spectrometer; GOME: Global Ozone Monitoring Experiment, HIRDLS: High Resolution Dynamic Limb Sounder, IASI: Infrared Atmospheric Interferometric Sounder, MAPS: Measurement of Atmospheric Pollution from Satellites, MIPAS: Michelson Interferometer for Passive Atmospheric Sounding, MODIS: Moderate Resolution Imaging Spectroradiometer, MOPITT: Measurement of Pollution in the Troposphere, NASA: National Aeronautics and Space Administration, OMI: Ozone Monitoring Instrument, SAGE: Stratospheric Aerosol and Gas Experiment, SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmospheric Chartography, TES: Tropospheric Emission Spectrometer, TOMS: Total Ozone Mapping Spectrometer, PICASSO: Pathfinder Instruments for Cloud and Aerosol Spaceborne Observation, UARS: Upper Atmosphere Research Satellite

Table 1. Major space-based tropospheric chemistry and aerosol data sets

| Sensors | TOMS/ TRIANA* | GOME | MOPITT | MODIS | SAGE III | SCIAMACHY | MIPAS | TES• | HRDLS | OMI* | MLS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| launch year | 1979- | 1995 | 1999 | 1999 | 2003 | 2001 | 2001 | 2002 | 2002 | 2002 | 2002 |
| $O_3$ | column | column | | | $\Delta z$= 1 km (UT) | column+, $\Delta z$= 3-4km limb | z>5 km limb | $\Delta z$= 2/4 km limb/nadir | $\Delta z$= 1 km (UT) | column | UT |
| $H_2O$ | column | | | | $\Delta z$= 1 km (UT) | column+, $\Delta z$= 3-4km limb | z>5 km limb | $\Delta z$= 2/4 km limb/nadir | $\Delta z$= 1 km (UT) | column | UT |
| CO | | | 3-4 levels | | | | z>5 km limb | $\Delta z$= 2/4 km limb/nadir | | | UT |
| NO | | | | | | | | tropical UT; $\Delta z$= 2 km | | | |
| $NO_2$ | | column | | | | column+, $\Delta z$= 3-4km limb | | | | column | |
| $HNO_3$ | | | | | | | UT | UT; $\Delta z$= 2 km | $\Delta z$= 1 km (UT) | | |
| $CH_4$ | | | column | | | column+, $\Delta z$= 3-4km limb | | column | | | |
| $CH_2O$ | | column | | | | column+ $\Delta z$= 3-4km limb | | | | column | |
| $SO_2$ | | column | | | | column | | column | | column | |
| $CO_2$ | | | | | | column+, $\Delta z$= 3-4km limb | | | | | |
| Aerosol | column | | | column | Column, UT | Column/profiles | | | | column | |

*TOMS has been in operation since 1979. Last launch was in 1996 and data continues to be collected at this time. Next TOMS launch is expected to be in year 2000. TRIANA and OMI will take over TOMS functions in year 2002. Much information on the AURA instruments (TES, HRDLS, OMI and MLS) is available from http://eos-chem.gsfc.nasa.gov/.

•A number of additional derived chemical products such as acetone, methanol, $H_2O_2$, HCN, $NH_3$, $HNO_4$, $SO_2$, and PAN are possible.

UT= upper troposphere

$\Delta z = 1 km$, UT